Compressed Air

DEVOTED TO THE USEFUL APPLICATION OF COMPRESSED AIR.

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Compressed Air

A MONTHLY PUBLICATION DEVOTED TO THE USEFUL APPLICATION OF COMPRESSED AIR.

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AT the convention of the Railway Master Car Builders and Master Mechanics held at Saratoga in June, compressed air furnished air power to a large number of Pneumatic Tools and appliances, and their operation was the object of much interest and comment. In view of the many uses to which compressed air is applied it is not visionary or improbable that a Compressed Air Expositon will some day, before long, be interesting and instructive. The success of the Electrical Exposition held a few weeks ago in New York, should urge the friends and promotors of compressed air to do something of the same kind in its behalf.

FROM all parts of the World come encouraging letters to "COMPRESSED AIR," commending its zeal in promoting the use of compressed air, and for the general appearance of the little magazine.

Advertisers too are beginning to see that benefits are derived by being represented in its pages. Each day since our last issue has brought us from one to nine paid subscriptions.

AMONG the latest things in compressed air are air mattresses and chair cushions for use in sleeping cars. The berths are equipped with these appliances and are luxurious indeed. They take up very little room and embrace every essential quality for cleanliness and sanitation.

When out of use the air is exhausted and they are laid away. When needed for use, air is admitted and a moment is sufficient to prepare them. With genuis employed in this direction we predict more comfort for humanity in congested communities.

He who occupies the "furnished" room may have a parlor by day and bed room by night. When Goldsmith reported the utility of the "Chest of drawers by day" that acted in the capacity of a "couch by night," he presaged the coming of appliances that duplicate their uses and economize space. Compressed air adds beauty, luxury and convenience to many other advantages.

Less than half a century ago two forces stood in mighty majesty before the gaze of the scientist and inventor, asking for recognition and for rule over the destinies of men.

As infants, both were cradled under the vault of a tropical sky, one in the shadow of the Pyramids, the other in the famous town of Magnesia in Asia Minor.

Their growth and development covered many centuries during which mummies stiffened, browned and crumbled, while the face of Asia changed at the smile or frown of the "Lion and Unicorn."

But in all the beauty and strength of maturing capability, they appear in this, the nineteenth century, writing our history in characters destined to make us forever honorable in the sight of future generations.

Their names are "Electricity" and "Compressed Air," and they perform their marvellous work in perfect harmony with their powerful brother, "Steam."

At first electricity dazzled the scientist and inventor by the fascination of her indefinite and mysterious possibilities, but the silent depth and power of her equally fair sister, compressed air, is now taking so firm a hold upon the imagination and judgment of the thinkers of to-day, that she bids fair to outstrip her rival in the race for dominion.

One of the first applications of the force of compressed air in this century was the pneumatic dispatch tube, and its inventor, George Medhurst, was regarded by his English compatriots as occupying an unenviably conspicuous position on the wrong side of that partition which, according to the poet, divides great wits from madness.

The success of his tubes for the conveyance of letters and light parcels, however, completely vindicated him from all taint of mental unbalance, and even though he failed in establishing an effective pneumatic railway in Great Britain, the Britons ended by admiring the man and standing in respectful attitude before the unlimited possibilities of the force. Indeed, such a hold did this power gain on the English mind that a proposition was considered by the Government of connecting Ireland and England by the "Pneumatic Dispatch Tube System," laid beneath the waters of the Irish Channel, in order to facilitate and expedite mail carrying. But the times were not ripe for its perfection, so the operations of the plan were suspended.

However, a line between the London and Glasgow telegraph stations was established, and an amusing anecdote is told of how an American at the Scottish town, who afterwards wrote his experience to the "Boston Transcript," first made acquaintance with the system.

Thinking that an error had been made in the transmission of his message to London, the gentleman in question desired to see the original blank. The operator, with an amused smile, told him that his message was then at the London main office. He replied, "Yes, yes, I know; but I want my own copy that I wrote out here about a half an hour ago." The clerk answered, "I understand what you mean, sir; but your copy has been in London for the past half hour, and if you will step here and apply your ear to this opening, I think I can convince you, in a few seconds, of the truth of my statement and show you your message." The operator then sent a dispatch, and presently the astonished listener remarked a peculiar whirring sound, and—he writes—"seventeen seconds later I heard the tinkling of a little bell announcing the arrival of the carrier, close at my ears, and in a moment more I had my original message in my hands."

He straightway became an ardent disciple of the new system, and led, doubtless, by the enthusiasm which characterizes most zealots, the American gentleman made several small misstatements, among them that of the time said to be consumed between the London and Glasgow stations. In point of fact, the carrier would have been required to attain a speed of four miles a second in order to cover the distance in question, and would have, moreover, been rendered red hot before the expiration of the first second. But allowance must be made for all converts, and as he was correct in his essential statements, let the mantle of charity, by all means, be extended.

Since the success of Medhurst's invention, America, that liberal patron of the best in every branch of advancement, has lent her encouragement to all new applications of the magnificent force of compressed air, and as a result, we have our coal and gold mined by this power, canals dug, rocks drilled, sunken vessels raised, sheep sheared, carpets dusted, cars cleaned

clocks and sewing machines run, ships steered, locomotives propelled, stone carved, and street railways operated. One is therefore constrained to ask, "Could electricity do more?"

FRANCES MALOY.

PUMPING BY COMPRESSED AIR.

Pumping water and other liquids by means of compressed air presents an attractive field for inventors, and a number have entered it with enthusiasm—some with undoubted success, while for the work of others it is yet too early to judge it fairly.

The attractive and most promising traits of compressed air for application to this purpose lie in the possibility of transmitting a great amount of energy an indefinite distance through small pipes, and then storing it for an indefinite time without serious loss; in the convenience, comfort and freedom from danger with which it can be applied; and, in some methods, the exceeding simplicity and cheapness of the necessary apparatus. One difficulty, not insurmountable, but requiring the utmost care in designing and in construction, is leakage of air. The other and chief difficulty lies in the loss of much or all of the energy of expansion possessed by the compressed air. In some designs there is no pretense of utilizing the energy of expansion either through ignorance of the extent of the loss incurred or through a desire to make a simple and cheap, and therefore a salable pump.

We may put all compressed air pumps into one of three classes:

First. Those that apply the air pressure indirectly through the medium of an engine with piston and piston rod exactly as in steam pumps.

Second. Those that apply the air pressure *direct* without the intervention of a piston, etc.

Third. Those that lift the liquid by the effect of bubbles liberated in a pipe.

To the first class belong the majority of pumps operated by compressed air. It is not the purpose of this paper to discuss that class, but it should be said that it is capable of all the variations found in steam pumps, with the one drawback that steam has not, viz., freezing when a high rate of expansion is attempted without reheating. While reheating is desirable to prevent freezing, and still more so to economize energy, it adds complication and cost, which must seriously retard its introduction in small plants.

The general action of the second class, direct air pressure pumps, such as are now on the market, can be understood by reference to figure I. Suppose the vessel submerged and filled with water. Now, if compressed air enters through the pipe C, the water will be driven out through the pipe A. When the vessel is thus emptied, a mechanism operated by a float will close the compressed air inlet and open an outlet so that the compressed air will escape into the atmosphere. As the air thus escapes, water will rise through the valve D, and refill the vessel. When the vessel is thus refilled, the compressed air inlet will again be opened and the outlet closed by some mechanism operated by a float, thus making the whole action automatic. Such pumps can be made of simple construction, with reasonable certainty of action and at moderate cost.

All these merits are apparent or can be easily demonstrated to a would-be purchaser; but the fault in such a pump is not so apparent nor so easily demonstrated. Moreover, the agent will be sure not to allude to it. This fault is the loss of all the energy of expansion. To show how serious is this loss the table below is inserted, showing the maximum theoretic efficiency for such pumps at different heights of lift. Of this not more than two-thirds, or at most three-fourths, can be realized in practice.

Height in feet to which water is lifted.	Maximum theoretic efficiency of air used without expansion.
34	0.72
68	0.61
102	0.54
170	0.46
238	0.42
306	0.39

It will be noticed that the efficiency of such pumps decreases rapidly as the lift increases; hence we may be justified in using such for low lifts where it would be folly to apply them to high lifts. There is a legitimate field for such pumps, but we should know its limit and keep them within it. In justice to such pumps it should be said that they can and should be more efficient, as well as more durable, than the non-expansive piston pump.

Inventors have attempted to make a direct air-pressure pump that will utilize the expansive energy of the air. The writer has discovered in the United States two

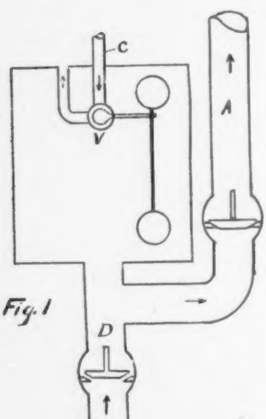


Fig. 1

Direct-Air-Pressure Pump

patents for such (Nos. 474,388 and 139,-538). In both, the complicated and imperfect mechanical details bar all possibility of success. However, the main idea—the same in both—is correct, and, in the writer's opinion, capable of being carried out successfully. This idea is to have two vessels of the general nature of that shown in figure I., and instead of allowing the compressed air to escape into the free atmosphere, it is, after the vessel is emptied, conducted back through the compressor and into the other vessel; thus using the same air over and over again, one vessel filling with water while the other is emptying. By this means it will be seen at once that none of the energy of expansion of the air is lost. The problem, then, remains to make the details simple, economical and sure of action. The problem is interesting from both a mechanical and an economical point of view. It also offers a good opportunity for "mathematical gymnastics."

We will now consider briefly the third class, in which water is raised by the effect of bubbles liberated in a vertical pipe. This has recently come to be known as the "Air Lift Pump," which name was given it by the "Engineering News" in an article of June 8th, 1893. (The article gives a very complete history of the air lift pump).

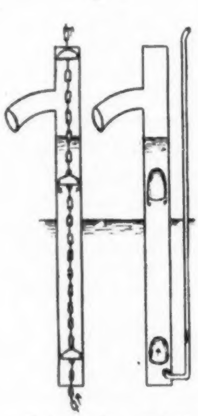
In construction it is the simplest of all pumps, the only essential being an open pipe, set approximately vertical with its lower end submerged, and some means of injecting air into the pipe below water-line. Each bubble of air liberated within the pipe, by virtue of its buoyancy, exerts a certain force upward, tending to lift the column of water within the pipe. It is the accumulated lifting force of a number of bubbles that produces the action of the air lift pump. From this point of view the general principle of the action is easily comprehended, but a mathematical analysis of its action with a view to determining best proportion, is by no means simple. * Indeed the difficulties are such that probably experiment alone will determine what are the best relations between depth of

* See "Theory of the Air Lift Pump," Journal of the Franklin Institute, July, 1895.

submersion, height of lift, volume of water discharge, volume of air used, area of discharge pipe, etc.

In this kind of pump, as in others, a large percentage of the energy put into the system may be lost through neglect of proper proportions and adjustments. A considerable proportion of the energy will always be lost by the bubble slipping through the surrounding waters, whether the whole be ascending or not. In this

Fig. 2



Chain and Button Pump — Air Lift Pump

respect the air lift pump is very similar to the well known "chain and button" pump as commonly used for lifting water from cisterns. In the latter we know that if the motion of the chain is too slow, all the water will slip by the buttons and remain in the cistern. So in the former: if the bubbles are too few or too small, or the lift too great, no water can be brought up. The difficulty lies in that the rubber buttons in the one case, and the bubbles of air in the other, *do not make water-tight pistons*. A bubble cannot be made to occupy the full cross section of a pipe under circumstances in which the air lift pump must act.

The writer is aware that a patent has been allowed for an air lift pump in which the claim is made that the bubble does fill the whole cross section of pipe, and that therefore they act as pipe-fitting pistons. The same claim is reiterated with great stress in all the literature on the subject issued by agents for said patent. If this claim can be realized for a series of bubbles, it can be realized with a single one. Does any one think it possible to make a single bubble remain stationary in a pipe under the given conditions? Or will it be claimed that when an air lift pump is in action and the air supply is suddenly cut off, that the "pipe-fitting pistons" of air will stand still in the pipe? Such must be the result if the claim is correct. Common sense, experience and science all oppose this claim. Let the advocates of the claim devise an experiment to prove it.

ELMO G. HARRIS.

Experiments with a glass tube, applied in the manner of the Air Lift Pump, will show clearly defined piston like sections of air and water, the discharge of air and water being intermittent and almost uniformly regular. When air is first admitted to the pump the water in the pipe above the point of air admission is blown out in a solid stream, as the shot is discharged from a gun.

If this is true, why may we not expect that the succeeding volumes of water which, through the head, are able to get above the air jet, are discharged in the same way? There is a continuous struggle going on between air and water to get into the eduction pipe, and notwithstanding the fact that air is admitted in a continuous stream its admission is not continuous, because the water at times practically shuts it off: These interruptions are however of very short duration.

The secret of the Air Lift Pump action is in the high velocity with which the air and water are discharged through the eduction pipe: Without this high velocity there would be no piston like sections except perhaps in a small glass tube model where capillary attraction takes the place of velocity.

Let us imagine a case where the eduction pipe is ten feet in diameter, and admit air—say through an 8 inch pipe—to a Pohlé foot piece, there will be nothing but bubbling of air up through the water and no piston like sections will be formed; but let us suppose that this air pipe is 5 or 6 ft. in diameter and that it has a free discharge under several atmospheres, is it not easy to understand, that under such conditions, the air might occupy the entire section of pipe and that it might discharge the water like a gun shot? Is it not also easy to understand that there will be a high velocity of movement excited upward through the eduction pipe and that we will either have a discharge of air alone, a discharge of water alone, or an intermittant discharge of both? This intermittant action takes place provided the air pressure at the foot piece is about equal to the water pressure due to its head. The two must be almost completely balanced, and it is because of a conflict for supremacy, or a change of pressure between air and water, which goes on at all times, that the piston like sections are formed. If it is admitted that these sections are formed at any time and that the velocity of movement upward is great, it is not difficult to understand the Pohlé Pump exactly as Dr. Pohlé invented and patented it.—ED.

In and about Railroad Machine Shops.

The sand blast is the most efficient means of cleaning paint scale and rust from tanks. No other way cleans out the pitting and around the rivets as satisfactorily.

A tender which had been repainted several times can be cleaned bright at the rate of a square foot in 7 minutes. A tank which had never been painted may be cleaned of rust at the rate of a square foot in 3 minutes.

At the Susquehanna, Pa., shops of the Erie R. R. Co., a Baird stay-bolt breaker saves 50 per cent. in time and one man at $1.40 per day. Two men and the pneumatic breaker can break 300 to 325 stay-bolts in 7 hours.

Stay-bolt tapper run by air saves 50 per cent.

Stay-bolt pincher or cutter operated by 2 men cuts 1,000 per hour on inside work. By hand one man can cut 300 in 4 hours.

Caulking and beading tool beads 235 2-inch flues in two hours and ten minutes. By hand 200 flues can be beaded in ten hours.

Mud ring riveter and two helpers at $1.40 per day each will do as much as two boiler makers at $2.30 per day each and one helper used to do in two days.

Riveting bull saves one man's time at $1.40. Bull also used to punch out old stay bolts after same have been cut. One boiler maker at $2.30 per day by hand can punch out 100 per day. Bull and two helpers at $1.40 each punches 300 in five hours.

Tank frame pneumatic riveter operated at 100 pounds pressure saves 50 per cent. Flue swageing machine for reducing flue end 1-16 inch for ferrule saves 50 per cent. in time.

At the establishment of Russell & Co., Massillon, Ohio, oil stored in tanks buried in the ground is forced by air pressure to store room where it is drawn from a faucet as required. This is a great convenience and minimizes the fire risk.

Stay-bolt cutter cuts 100 ¾-inch bolts in one-half hour, by hand 100 to two hours is the average. When stay-bolt cutter was introduced a reduction of 60 per cent. was made in the pay of men doing this work and still they now make 6 per cent. more wages than before the reduction.

The cutter does not loosen the stay like chipping by hand is likely to do.

THE Chicago, Peoria & St. Louis R. R. Co. use air for lifting at axle lathe and wheel press and the saving amounts to about 50 cents per day in the services of two men. Emery grinders and buffing wheels are also used to great advantage. The saving in cleaning the brass in one coach with this buffing wheel run by compressed air amounts to $1.25 over hand work and a much better job is done. A set of flues is beaded in one-fourth the time formerly required.

A Right Way and a Wrong Way to place Compressed Air in competition with Electric Power for Street Railways.

The indications being that compressed air will be experimentally used for practical street railway operation at an early day, it should be earnestly hoped by all friends of compressed air, and especially by those who are interested in its introduction as a motive agent, that it will be so experimentally introduced as to give a reasonably fair impression. The use of compressed air for street car propulsion has hitherto been regarded with distrust and prejudice, for several reasons. It may be reasonably hoped that a fair trial of compressed air for this purpose, under circumstances that will do it justice, will, to a large extent, remove this prejudice and draw attention to the advantages of such a motive power. A number of important requisites to the fullest success of a compressed air system for street railway operation might be profitably considered. These features vary somewhat in importance in different systems which have been proposed. There are, however, two considerations which apply with equal force to all compressed air systems, and it appears desirable to draw attention to their importance at this time. The two features referred to are, first, the pressure at which the compressed air is stored upon the cars, and second, the suitability of compressing apparatus for charging the cars. These two matters may properly be considered simultaneously.

The only apparent practical method of using compressed air for street car propulsion is that known as the storage system. In every case where air is stored in reservoirs upon the cars for this purpose, the air is admitted to the motor cylinders at a moderate pressure and is stored in the reservoirs at a considerably higher pressure, in order to enable the car to be run some distance without renewing the supply of air. There are two ways of increasing the mileage of a car with one stored charge of compressed air; one is to enlarge the reservoir volume for storage, and the other is to increase the pressure of the stored air. For practical reasons, the size and volume of storage reservoirs is limited and the temptation to store the compressed air at high, pressures has consequently been great, in order to cover long distances with one supply of air. If the absolute pressure of the stored air be doubled, the available power, at the reduced pressure for the motor, is doubled; but in thus doubling the stored power, the cost of the compressed air supply has been very much more than doubled. After compressed air is stored in the reservoir, the temperature of that air becomes practically the same as that of the external atmosphere. Each cubic foot of air so stored, at an absolute pressure of p pounds per square inch, has required, in the process of compression and delivery into the reservoir, the expenditure of work, which, in a properly designed compressor, is represented by

$$W = 144\,p\,\frac{sn}{n-1}\left\{\left(\frac{p}{14.7}\right)^{\frac{n-1}{sn}} - 1\right\}\text{ foot lbs.}$$

In this formula, s represents the number of stages during compression, with complete cooling of the air to atmospheric temperature between each two consecutive stages; and n is a number not exceeding 1.408, and is usually a trifle less.

If the air be subjected to no cooling influence whatever during compression in the air cylinder, the value of n is 1.408. For practical reasons, it is always customary, in compression plants of any considerable size, to water jacket the air cylinders, which exerts a cooling influence, in greater or less degree, upon the air during the period of compression. Where the compressing cylinders are very small, it is not improbable that the cooling effect, due to the water jacket, is a very material one; but it has been fully demonstrated that

where large compressing cylinders are used, as would be the case in a compressing plant of suitable proportions to supply a street railway system with compressed air, the cooling influence of the water jacket upon the air during compression is quite small. In view of the fact that more or less loss occurs by leakage past the air piston and valves, it may, without any material error, be assumed that the cooling influence of the water jackets about offsets these losses, and the valve of n should therefore be regarded as 1.408.

The number of stages which should be employed for compression depends upon the final pressure and the quantity of air to be supplied. When a large quantity of compressed air is to be supplied at a high pressure, an economical performance of the compressor can only be obtained by compressing in several stages. For the purpose under consideration, the final pressure being 500 lbs. or more, the number of stages should not be less than three or four.

Assuming that the compression occurs in four stages, the following table shows the foot pounds of work expended upon the air for each cubic foot of compressed air stored at atmospheric temperature and different storage pressures, from 500 lbs. to 2,000 lbs. Indicating by w the foot pounds of work which may be done in the motor by one cubic foot of air stored at 500 lbs. pressure, the table also shows the relative amounts of work that can be performed in the motor by one cubic foot of air stored at the various other pressures. Also, representing the efficiency of any system, when operating with a stored pressure of 500 lbs., by E, the table shows the relative efficiencies of the same system with greater pressures of storage.

Storage Pressure by Gauge.	Work Expended. (W)		Work Restored by Motor.	Efficiency.
	Foot lbs.	Rel've.		
500 lbs.	300 600	1.	1.000 w	1.000 E
1,000 lbs	724 100	2 409	1 971 w	.818 E
1.500 lbs.	1 201 300	3.997	2 943 w	.736 E
2,000 lbs.	1 714 800	5.705	3 914 w	·686 E

It will be seen from this table that the efficiency of the system diminishes very rapidly as the pressure of the stored air is increased. Whatever the system itself may be, and regardless of what its actual efficiency may be under any stated conditions, the efficiency of that system will vary somewhat more than is indicated by the table. The reason for this is that the greater the pressure of storage, the more difficult will it be to prevent loss by leakage, and consequently the incidental losses due to leakage, etc., will be increased by the higher pressures, with the result that there will be a greater difference in the actual efficiencies, with different storage pressures, than is shown by the table.

To indicate the fact that the conditions are less favorable to economy for all storage pressures, but especially so for the higher storage pressures, when the air is compressed in a smaller number of stages, the following table has been prepared, for single stage compression :

Storage Pressure by Gauge.	Work Expended. (W)		Work Restored by Motor.	Efficiency.
	Foot lbs.	Rel've		
500 lbs.	461 500	1.535	1.000 w	.651 E
1,000 lbs-	1 217 500	4.050	1.971 w	.487 E
1,500 lbs.	2 134 000	7.099	2.943 w	.415 E
2,000 lbs.	3 163 600	10.544	3.914 w	.371 E

It will be seen by a comparison of the two tables, that good commercial economy is absolutely out of the question without the use of suitable multiple stage compressing machinery. It will be equally evident that a system which might compare very favorably in point of efficiency with

the electric trolley systems, when operating under a storage pressure of 500 lbs., would be hopelessly out of competition in this direction if operated with a storage pressure of 2,000 lbs.

Attention is called to these matters more especially on account of the evil influence of the wholly incorrect and mis leading statements which have been made by those who desire to befriend the use of compressed air. It has been stated, by at least one writer, that the increased cost of supplying compressed air for storage at high pressures is insignificant in comparison with the advantage of the increased mileage due to a single air supply. In comparing the cost of compressed air power with that of horse power for street railways, such a statement may perhaps be excusable; but in comparing compressed air with electric power, such a statement is absolutely unfounded and is extremely dangerous, in that it may be influential in condemning the use of compressed air altogether in the event of the failure of a high pressure storage system.

It cannot reasonably be expected that the efficiency of the electric trolley system can be materially surpassed by that of a compressed air storage system operating under the most favorable conditions; and it is certain that it cannot be nearly approached by a compressed air system which stores air at such high pressures as have been recently proposed, or in which the compressed air is supplied by anything but a high grade compressing plant. It will be far better to store air at a moderate pressure and to attempt only a moderate car mileage between successive chargings. This will, in many cases, require additional charging points, which may be supplied either by additional compressing stations or by carrying the compressed air in pipes from a central compressing station to local charging stations; but there can hardly be any doubt that the cost of operation will, in the long run, be very much reduced by this plan.

Nothing is now said regarding any collateral advantages in the use of compressed air for street railway operation; it is simply desired to point out that there is a right way and a wrong way to place compressed air in competition with electric power. It is to be hoped that compressed air enthusiasts will not give the future of compressed air a black eye by adopting the wrong way.

R. A. PARKE.

Economies effected by Compressed Air.

In an article by C. W. Shields, published in the *Railway Age*, Mr. J. H. McConnell, Sup't, M. P. Union Pacific R. R., is credited with furnishing the following summary of time and expense saving in various shop practices when done by compressed air.

	Saving per day.
Putting wheels in wheel lathe, three lathes in the shop an average of one change a day, save one man in handling this work..............	$1 60
Hoisting steel-tired wheels and axles in lathe, average of six changes a day, save one hour in time, $1.60; and one man less to handle the work, .20.............	1 80
Hoisting axles into cut-off lathe, an average of ten changes a day, save one hour per day in time.........	.25
One large boring mill averages two changes a day, 1.60; saving of time of 30 minutes and the use of one helper, .15..................	1 85
Handling cylinders in large boring mill and planer, save the labor of one man and one-half hour each change......................	1 60
Three men working on pistons, etc., in raising them from the floor to the bench, serving three machinists, save one helper five hours a day........................	.80
Raising chucks, face plates, and other heavy work, air hoists in the machine shop save one helper one day........................	1 50

Lifting driving wheels and other heavy work on the large slotting machine, save the time of one man and 20 minutes	1 50
In applying cylinders on boilers, save one machinist and helper's time of 10 hours	2 40
Facing valves, save helper's time of four hours	.60
Pressing on driving wheels and axles, etc., three less helpers one hour each	.45
Boring out cylinders, three helpers' time four hours	1 80
Applying driving brakes to old engines, drilling holes, reaming, etc., saving 15 hours of time of machinist and helper	6 70

Pneumatic tin and galvanized iron press, in getting out stock for 20 dozen water buckets, get it out in eight hours where it previously took 40 hours.

In making brake shoes stamping a loup to have casting run on, previously one man would do 200 in a day where he now does 600. All work on this machine saves in the neighborhood of from 50 to 60 per cent.

Running foundry elevator with the air hoist saves 25 per cent. of one man's time.

Save 75 per cent. time putting in stay bolts in a fire box by using air motor for tapping out holes and screwing in bolts.

Save in the neighborhood of 50 per cent. in using pneumatic hammer for caulking both flues and boilers.

Take engines in and out of roundhouse when necessary to change them, saves the work of six men pinching possibly 45 minutes, not counting the delay of the men waiting to go back to work on the engine.

Blowing out engines with air, save a cord of wood, besides the inconvenience and delay, as the men cannot work around a hot engine to advantage.

Handle all engines on the transfer table now run by air, previously run by crank. One man does now what six did before; where six men move a foot in a minute, air motor under like conditions will move twelve feet. As this is moved several times a day, this in itself is a great saving.

Pneumatic hoist for unloading scrap at the foundry, the old method took six men 10 hours; under the same conditions with the hoist, two men will do it in 4 hours.

Unloading a car of wheels, it takes six men half an hour; now three men will do it in 15 minutes.

Sandpapering off a 50-foot baggage car by hand took in the neighborhood of 60 hours; now it takes 14 hours with the sandpapering machine.

Air jacks for raising and lowering freight cars now take one man three minutes where previously it took two men ten minutes.

Truck jacks to remove three pairs of wheels takes 1½ hours; the old method takes 6 hours.

Cleaning a car save about 10 per cent. in time and 90 per cent. thoroughness.

Air whitewashing machine, where it took ten men five days it now takes four men one day, and a 75 per cent. better job.

THE Baldwin Locomotive Works ream all boiler rivet holes from one-sixteenth inch smaller to one-thirty second inch larger than the rivet. The Phœnix air reamer does this in one-half the time required by hand. Tapping is done in one-third the time. Inserting 60 one-inch stay bolts in throat sheet took five hours by hand and two and one-half hours with air tool; water space six inches, eighty pounds of air pressure is used. Reaming crown of boiler takes five to six hours by hand and three to three and one-half with air machine.

They have twenty-one machines cutting stay bolts and nine on reaming, and consider they save one-half the time required by hand formerly. They use a compressed air white-washing machine, and find it works five times as fast as by hand. In addition to making an absolutely dead white surface, it fills up all the cracks and crevices, thereby killing all the vermin that infest such retreats.

Compressed Air as Used for Power Purposes.

A Lecture delivered before the Engineering Society of Columbia College, on April 22d, 1896, by Frederick C. Weber, M. E.

(CONTINUED.)

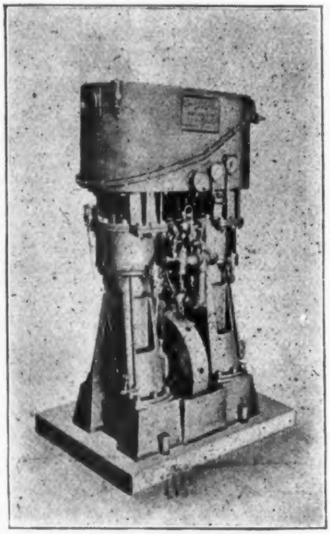


FIG. 7.

RAND HIGH PRESSURE COMPRESSOR.

The air cylinders are all enclosed and surrounded by water. Three gauges are shown which record the pressures of the different cylinders.

INGERSOLL-SERGEANT FOUR STAGE COMPRESSOR.

Fig. VIII. represents a four stage compressor (with intercooler) attached to a Corliss engine. The cylinders are single acting, and are fitted with plunger pistons. A compressor of this type will compress one cubic foot of free air per minute, from 15 pounds to 2,000 pounds per sq. in., at a power cost of .4-10 horse power and 1.3 lbs. coal per 100 cubic feet of free air. There are three intercoolers, each of sufficient size to reduce the temperature of the air at the end of compression to normal temperature.

USE.

Having thus shown how the air is compressed and by virtue of which energy is stored, our attention is next turned to the utilization of this stored energy.

The intrinsic energy of one pound of air at atmospheric pressure and temperature of melting ice, may be shown to be by the following formula:

$$C_v\ T_o = \frac{p_o\ v_o}{n-1} = 64{,}735 \text{ foot pounds.} \quad \text{VIII.}$$

C_v = Specific heat at constant volume.
T_o = Absolute temperature of melting ice.
p_o = Mean pressure of atmosphere in pounds per sq. ft.
V_o = Volume of 1′ at p_o and T_o.
n = Ratio of specific heats = 1,406.

Since the heat of compression due to the mechanical energy expended upon the air by the piston is usually dissipated to the surrounding objects before the air reaches the motor, and for which we therefore get no mechanical equivalent, we are obliged to draw upon the *intrinsic energy stored* in the air if we wish to get any useful return for the work expended.

WEIGHT OF AIR USED.

The number of cubic feet of free air used per minute for a given amount of work may be determined as follows:

$$C = \frac{W}{w} = \frac{33{,}000\ N}{U\ w} \quad \ldots\ldots\ldots\ \text{VIII.}$$

W=Weight of air per minute to deliver N horse powers per minute.
w=Weight per cubic foot at atmospheric temperature.
U=Work in foot pounds per pound of air.

The value of U will depend upon complete or incomplete expansion, or upon full pressure working:

$$U = P_2\ V_2\ \frac{n}{n-1}\left[1 - \left(\frac{P_A}{P_2}\right)^{\frac{n-1}{n}}\right]\left(\frac{T_3}{T_2}\right) \quad \ldots\ldots\text{IX.}$$

P_2 = Initial pressure.
V_2 = Corresponding volume.
P_A = Exhaust pressure.

(No allowance for clearance, leakage and valve resistance.)

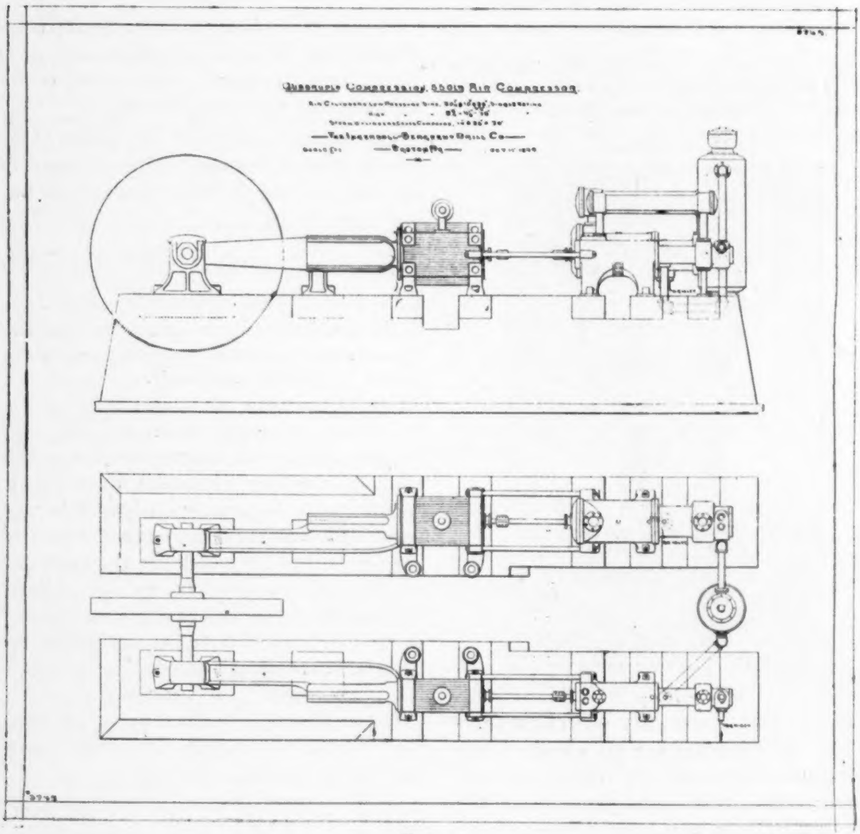


FIG 8.

INGERSOLL-SERGEANT FOUR STAGE COMPRESSOR.

From experiments made with reheating air at a point very close to its application, it has been found that U may be increased in proportion to the heat imparted, or in the ratio of—

$$\frac{T_3}{T_2} \text{ (absolute temperature.)}$$

Since any increase in the value of U will effect a corresponding decrease in C (number of cubic feet used per minute), the aim of the practical engineer should be directed towards reheating and expansive working. The cost of reheating is about one-eighth of a pound of coal per horse power per hour.

AIR MOTOR.

Most air motors in use at the present time have been designed after the steam engine; in fact, the steam engine is often converted into an air engine with very good results. Considering, however, the difference in the properties of both fluids, there is no doubt that higher efficiencies can be attained when the motor is especially designed for the use of air.

Fig. II. represents also a theoretical card taken from an air engine, and shows the volume of air taken in at the compressor to be contracted from C to D, due to fall-

ing temperature, and when it reaches the motor it is about 60° F. If it is used expansively, then the expansion line will be (D R); great cold will result, and the theoretical temperature at R will be about -155° F., and if moisture is contained in the air it will cause freezing of the exhaust ports, unless provision is made for abstracting it.

If heat could be supplied during expansion we would be able to trace the isothermal D B, and there would be no loss at all. This is impossible, of course, and the efficiency is, as here shown, about 50 per cent. Now, if the air is heated before it is admitted to the motor, the volume would increase from D to C, and if expansion took place along C B (adiabatic), we would get back all the work that was put into the air in the compressor, taking out, of course, valve resistance and other losses incident to transmission. Continuing this argument, if it were possible to use the air in the motor-cylinder at temperature above 350° to 400° F., we would be able to obtain more work from the air than was originally expended upon it, at a very small additional cost for reheating.

SERGEANT AIR REHEATER

FIG. 9.

We have just seen that by reheating the air we increase its energy in proportion to the heat applied, or—

$W=Cp(T_1-T_2)$ foot pounds of energy supplied to every pound (at constant pressure.

Aside from this thermo-dynamic gain, we also overcome the danger of freezing at the exhaust port in the motor, for the temperature of exhaust is raised above that of the freezing point.

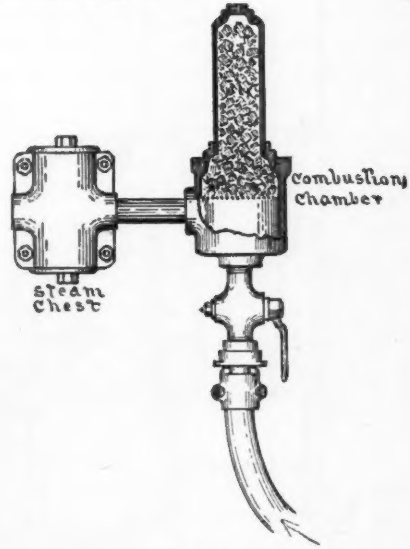


FIG. 10.

REHEATERS.

There are various practical methods of reheating. The most prominent are:

I) Applying heat through metal surfaces.

II) Internal reheating.

SERGEANT REHEATER.

One of the first class is shown in Fig. IX., and is known as the Sergeant Reheater. This reheater consists of two cast iron shells, which are bolted together. Air enters the annular space at the top and passes in thin layers over the walls of the heater into the annular space at the bottom, which forms the outlet. In appear-

ance it resembles a truncated cone. The advantage of this form is to keep the velocity of the air constant. The air being hot, it has greater volume, and would consequently increase the friction if there was no room for expansion. The fuel may be either gas, oil or coal, or coke; when made for coal or coke, it will be supplied at the top, and the ash will be drawn from the bottom.

SAUNDERS' INTERNAL REHEATING.

Fig X. represents a reheater of the second class, known as an internal reheater—i. e., where the air comes in direct contact with the fire. This illustration represents the reheater actually applied to a rock drill. It is placed between the throttle valve and steam chest. and represents an enlarged pipe fitting, with a wire gauze to keep the coal or coke, which is in an incandescent state, from blowing into the steam-chest. Coke or charcoal is supplied through an opening at the top, which is then securely fastened. This method of reheating ought to be very economical and effective. The air supplies the oxygen

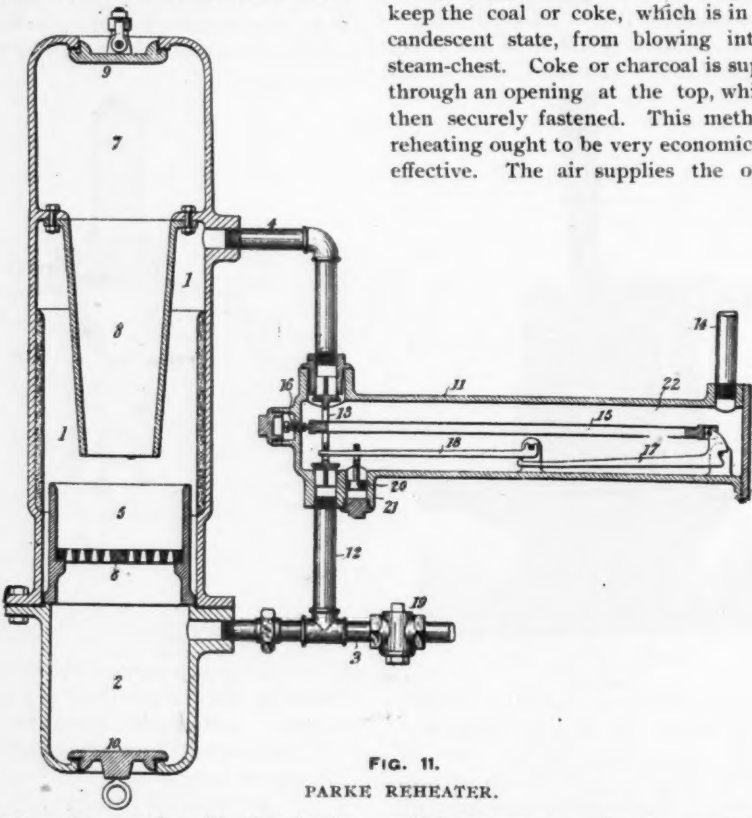


FIG. 11.
PARKE REHEATER.

Tests have been made with this heater, and the results show that 340 cubic feet of free air per minute, at 40 pounds pressure, can be reheated to 360° F. This is equivalent to a gain of 35 per cent. imparted to the energy of a pound of air. The capacity of this reheater is given as 400 cubic ft. of free air per minute.

which promotes combustion, and the resulting heat is transmitted direct into the motor cylinder.

PARKE REHEATER.

In the Parke Reheater, shown in Fig. XI., fuel is admitted at 9; 8 is a hopper, and 5 the grate; 2 the ash pit, and 10 an opening to blow out ashes. The air is supplied

through the pipe 3, and it passes over hot coals and out through pipe 4, then into a thermostat; 15 is a bar made of metal, with a high coefficient of expansion; 13 is a double valve, and 14 is the outlet; 16 is a regulating screw. When the temperature is too high, the bar 15 expands, and, working through levers, 17 and 18 helps to shut off the supply of hot air and at the same time admits cold air through 12, thus reducing the temperature and keeping it uniform. The adjustment can be made so that the temperature will not vary 5 degrees. There is necessarily a limit to the temperature of the air at which it may be admitted to the motor, and this is about 300° to 350° F. The pipe for transmitting the air will have to be well covered to keep the air heated at this high temperature, as air parts with its heat as easily as it takes it up.

pipe in the top of the tank and then out into the cylinder. The advantage of this steam in the cylinder is twofold—(a) lubrication of cylinder and preventing leakage past piston; (b) the air in expanding draws upon the latent heat of the steam, and therefore brings the expansion nearer to the isothermal.

TABLE FOR REHEATING.

Fig. XIII. shows the comparative values of different methods of reheating, as determined by experiment at Frabrick street, Fargeau. The hot air and water injection method seems to have given by far the best results, the efficiency of the fluid being almost double that of the cold air.

SEPARATOR.

Sometimes it is not practical to reheat the air, especially when the motor is being moved from place to place; and then if the

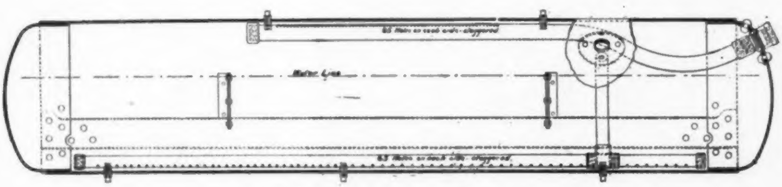


FIG. 12.
HARDIE REHEATER.

motor works air expansively, the danger due to freezing can be successfully overcome by means of a separator placed in the pipe near the motor.

Another method of reheating, and one which has met with a very high degree of success, both in this country and abroad, is a system of passing the air through hot water under pressure on its way into the motor cylinder (Fig. XII). This system is in vogue in the Hardie motor, and has given good results, some of which are given in the table (Fig. XIII.)

The water in this tank is heated by blowing a jet of live steam into it, and the air passes through fine openings into the water at the bottom of the tank. In passing through the water the air takes with it some of this water in the form of vapor, passing through the perforations in the

An experiment was made at Cornell University, with which I am familiar, to operate a small slide valve engine with air at an initial temperature of 40° F. A separator was made out of a 6-inch pipe, with caps on both ends. The air was drawn from this separator at right angles to the supply; the moisture in the air was thrown against the sides of the separator and ran to the bottom, where it was drawn off from time to time by a small drip-cock. This experiment was successful, and the engine

FIG. XIII.

Comparative Tests of Compressed Air Motors at Fabrik St. Fargeau, using cold air, hot air, and hot air with water injection.

DESCRIPTION.	Cold Air.	Hot Air.	Hot Air and Water Injection.
Weight of air used per I H. P. per hour in cylinder	63.65 lbs.	45.526 lbs.	33.59 lbs.
Volume " " " " " measured at exhaust....	822.7 cu. ft.	586.14 cu. ft.	432 55 cu. ft.
Volume of air used per I. H. P. per minute..........	13 7 "	9.76 "	7.2 "
Temp. of compressed air (inlet)..........	62° F.	392° F.	392° F.
" " (exhaust)...........	—67° F.	32° F.	122° F.
Total efficiency of fluid.	46.2 p. c.	64.8 p. c.	86.9 p. c.

(Abstract from paper of Jos. Francais in "Seraing Belgien," 1888.)

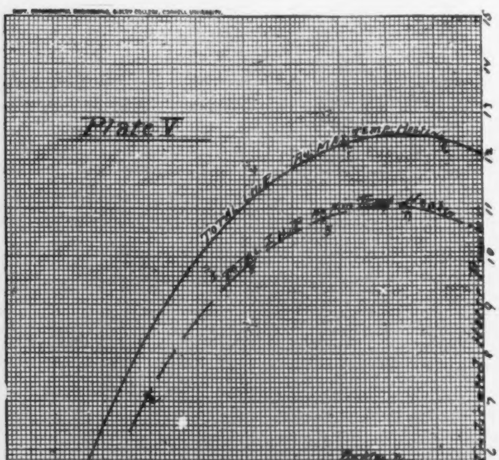


FIG. 14.

The consumption of free air per minute, when reheated, has been stated for the Paris air motors, by a writer of authority, to be from 11 to 15 cubic feet per I H. P. per minute, and when using air cold, 15 to 25 cubic feet per I H. P. per minute.

HARDIE MOTOR.

In the Hardie Motor tested by W. K. Lanman and myself in May, 1895, we found the consumption of free air per minute to be from 6 to 6.7 cubic feet per I H. P.

In this test our object was to determine the most economical working pressure, and also to determine the efficiency of the reheater. We made 7 runs with initial pressures ranging from 55 pounds to 140 pounds per square inch. Every other condition was kept as nearly constant as possible. The air was passed through the hot water in the reheater, but as the heat stored in the water was gradually becoming less, the efficiency diminished from beginning to end of run. This can be shown by a set of curves we have drawn from data of experiment Fig. XIV.

Fig. XV. shows some results of tests of the Hardie Motor.

did not stall when we reached as low a temperature as 3° F. (A lower temperature might have been reached but for the fact that the engine was cuttingoff at ¾ stroke.)

FIG. XV.

Abstract from Test of Hardie Motor, at Rome, N. Y., May, 1895.

NUMBER OF RUN.	I.	II.	III.	IV.	V.	VI.	VII.
Av'ge working pressure lbs., sq. in.	54 6	69.6	91.9	100 2	116.8	141.	133.
Distance run in miles	1.14	2.49	2 96	3 27	3.25	3.58	1.57
—Reheater—							
Temp. of air entering heater.....	78° F.	70.8°	67 6	61.5	63.	65 2	71.
Temp. of air leaving Heater	210°	248	197.5	247 5	197.	240 3	196.7
Temp. of air at Exhaust	127°	148.6	108.	146 7	104.4	130 7	99.
Degrees taken up by air in passing through Heater	132°	177.	129.9	186.	134	175.1	125.7
Difference in temp. in Heater, begin. and end run.............. ...	18°	21	30	47	28	49	16
Indicated horse power.......	3	7.1	9.79	11.9	10 86	12 45	11.19
Pounds of water used during run...	15 08	25.7	30.35	27 6	12.1	29.37	10 05
Air used per I H. P. per min., cu. ft.	7.7	6.4	6.1	6.1	6.6	6	6.7
Per cent. of power obtained from Heater......	41.4	46.5	32.5	47.	36.	43 2	34 6
		I.	II.	I.	II.	I.	II.

There were two runs made with one charge of hot water. and the second run in each case necessarily shows a lower efficiency, due principally to loss of heat from the reheater. If the reheater could be supplied with heat during the entire run, there is no doubt that the above figure of 6 cubic feet per minute can be still further reduced. The power obtained from the reheater was about 45 per cent. of the total power developed. We made one run without hot water in the reheater, but as the temperature of the tank was still above 100° F when we started our run, the consumption of free air per minute was 8.8 cubic feet. Other experiments made since, show that when the tank is at atmospheric temperature the consumption is about 12 cubic feet, so that when this motor is working with cold air it is as economical as the foreign motors, of which we have given figures above, working hot air.

In the Hardie Motor the air is compressed to a pressure of 2,000 pounds per square inch. It is stored in Mannesmann seamless tubes, which are shaped like a bottle with a round bottom. At the neck copper tubes are screwed in securely, and there are 16 tubes and each 7½ inches diameter, but of different length, so as to utilize all dead spaces under the car body. These tubes are tested to 4,000 pounds pressure, and are all connected so as to form one receiver. The capacity in cubic feet is about 45, which means that the free air capacity is about 6,000 cubic feet. The car will be able to travel about 15 miles on one charge.

The power to compress 6,000 cubic feet per minute in a four stage compressor will be about 3,000 H. P., if done in one minute, and in 5 minutes it will take a 600 H.P. compressor.

Since it is not practical to use air at such high pressures in the cylinder, on account of losses due to clearance, this pressure is reduced by means of a reducing valve, and air is admitted to the reheater and then to the cylinder at about 140 pounds per square inch. This great loss, due to wire drawing, is compensated for in the storage for with such a supply (6,000 cubic feet) there need be no delay and inconvenience due to recharging until the power house is reached.

If it could be arranged to keep the water heated throughout the run, there is no doubt that the efficiency of this motor would be very much increased.

Chairman—If any of the members desire to ask Mr. Weber any questions, I think he will take pleasure in answering.

Student—I should like to ask Mr. Weber

how these air motors compare in efficiency with other forms of motors?

Mr. Weber—The efficiency is high. The compressed air motor is usually as high as that of the steam engine; and, as I said, if special designs were made for air, they would be still higher. There is a report published of tests made in Paris by Prof. Unwin, on small rotating air motors, and I think it showed from 80 to 85 per cent. I don't know the exact figures.

Student—In that reheater you spoke of, invented by Mr. Saunders, where the air comes in direct contact with the heated coals, I should think there would be trouble from ashes being carried into the cylinder.

Mr. Weber—Mr. Parke overcomes all that. I think his reheater is an improvement over Mr. Saunders' reheater, for he furnishes a constant supply at constant temperature, which is very important at times; but Mr. Saunders' idea is a good one for such rough work as with drills.

Student—I should think some sort of electrical reheater could be used.

Mr. *Weber*—I can refer you to an article by Mr. Wm. L. Saunders in "Cassier's Magazine," 1892, a reprint of his lecture on compressed air before the Franklin Institute of Philadelphia he speaks of some electrical devices.

The Society tendered its thanks to Mr. Weber.

COMPRESSED AIR.

(CONTINUED.)

It is theoretically possible to realize out of compressed air more power than was expended at the compressor. This has been shown in Fig. 1, but that this statement might not be confused with perpetual motion theories the sketch shown in Fig. 4 has been prepared.

Sulphuric acid in its cencentrated form will, when exposed in an open dish absorb moisture from the atmosphere to the extent of about double its weight. A hypothetical assumption is made of a pump arranged to discharge sulphuric acid in the direction shown by the arrow to an open dish, elevated (say) 100 feet.

The amount of power necessary to discharge a certain quantity of sulphuric acid into this dish is exactly equal to the power which the sulphuric acid is capable of giving out when falling back again, less the friction of the pump, leakage, etc. Now, let us assume that the sulphuric acid in the open dish remained there long enough to absorb moisture from the atmosphere until its weight has been doubled; it will thus obviously have twice the amount of power in falling back again, and if the friction and leakage losses were not too great it will be capable of driving the pump and of returning an equivalent volume of the concentrated acid to the dish. If the same acid is used over again, the moisture must be driven out, and lamps are shown in the sketch provided for this purpose. The analogy between this hypothetical case of sulphuric acid and one of compressed air is, that, as with acid we may draw power from moisture which is contained in the air, so with compressed air may we draw upon

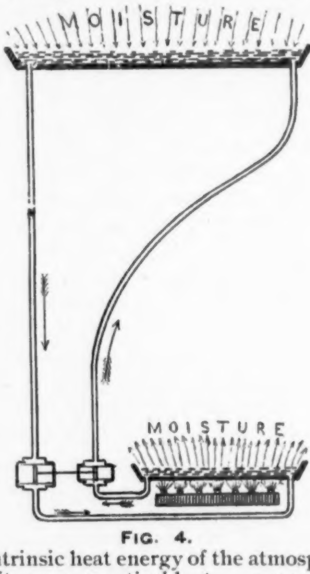


FIG. 4.

the intrinsic heat energy of the atmosphere.

If it were practicable to compress air isothermally—that is, without heat—we might illustrate the point referred to in the foregoing by placing an air compressor in a cold room, or what would amount to the same thing, taking in cold air to the cylinder of the compressor, this air being taken, for instance, from a cold storage room, and on being compressed the temperature being maintained at the initial point. This cold compressed air might then be led in pipes placed on the surface of the ground and exposed, say, to the hot sun, so that when used its temperature might be largely increased above that at the compressor.

W. L. SAUNDERS.